Journal of Physics: Conference Series



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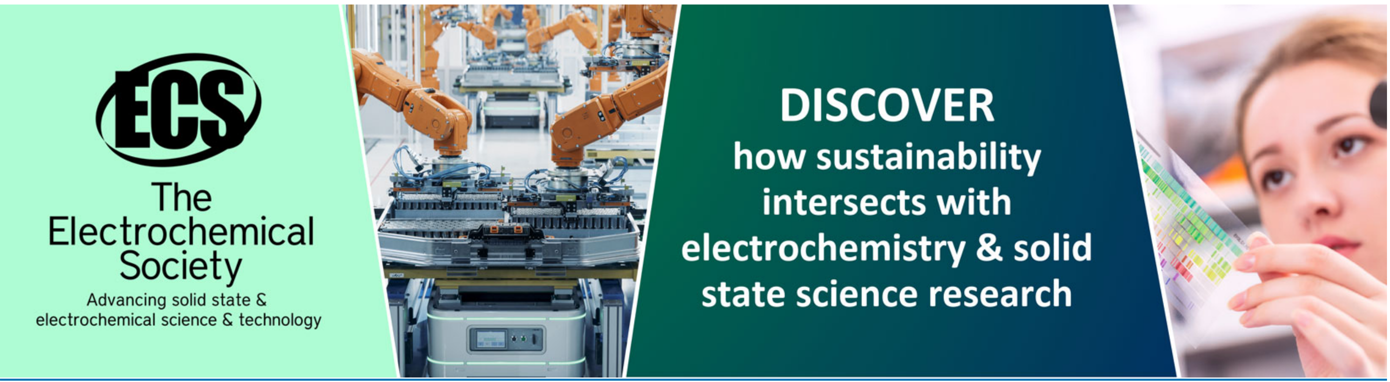
To cite this article: S V Terebilov *et al* 2019 *J. Phys.: Conf. Ser.* **1210** 012139





# Fire-tube boiler heat exchange surfaces fouling formation

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**Abstract.** The paper deals with the main types of foulings on the boilers heating surfaces. The mathematical modelling of the fire-tube boiler processes including the fouling formation was carried out. The fire tube design making it possible to reduce the fouling formation velocity is proposed.
Key-words: fouling formation, heating surfaces, freely soluble compounds deposits, fire-tube boiler

## 1. Introduction

While operating the fire-tube boilers, foulings contributing to the thermal resistance coefficient increase are formed on the heat exchange surfaces [1-3]. It results in the wall temperature growing. Fire tube wall temperature increase can cause the boiler failure and destruction [4, 5].
For defining the fouling influence on the heat transfer process, the following equation of the heat transfer coefficient can be recorded [1-3]:

$$k_f = \frac{1}{\frac{S_o}{S_i \alpha_i} + \frac{S_o}{S_i} R_{fi} + \frac{S_o \ln(d_o / d_i)}{2\pi\lambda L} + R_{fo} + \frac{1}{\alpha_o}} \quad (1)$$

where $S_i$ is the heating surface area on the combustion products side; $S_o$ is the heating surface area on the heat carrier side; $\alpha_i$ is the total heat transfer coefficient on the gas side; $\alpha_o$ is the heat transfer coefficient on the heat carrier side; $R_{fi}$ is the fouling layer thermal resistance on the combustion products side; $R_{fo}$ is the fouling layer thermal resistance on the heat carrier side; $\lambda$ is the wall material thermal conductivity coefficient; $d_i$ is the heating surface inner diameter; $d_o$ is the heating surface outer diameter.
In equation (1), the thermal resistances of the inner and outer heating surfaces foulings are the functions dependent on the thermal conductivity and fouling thickness.
The given formula reveals that the additional thermal resistance contributes to the heat transfer coefficient reduction.
The analysis of the literature data [1-7] shows that there are no dependences of the formation rate on the fire-tube boiler heating surfaces. Therefore, there is a need to define them for taking into account when designing the fire-tube boiler.
The problems of fouling formation on the boiler units heat exchange surfaces are considered in a number of papers [5, 6]. The fouling composition can be grouped into the following main ones: iron oxide deposits, alkaline earth deposits, copper compounds deposits, aluminum deposits and freely soluble compounds deposits.

## 2. Problem statement

In the fire-tube boilers, where water and steam-water mixture moves only due to the free convection, the friable sodium deposits (of the freely soluble compounds) accumulate on the upper surface of the fire tube and gas-tube bundles tubes, as well as in the boiler bottom. Moreover, under the intense fouling accumulation, the distance between the lower generating line of the fire tube and boiler bottom can become completely clogged with fouling and the fire tube can overheat resulting in the metal strength loss and boiler failure. To prevent this, steam boilers and hot water fire-tube ones should be regularly blown out. At the make-up water average salt content at the level from 350 to 500 μg/kg and at the above standard value of the hot water boilers make-up (2-3% of the network water flow), the distance between the fire tube and 250 mm boiler bottom becomes clogged during 2 years. When make-up is more than 5%, the boiler can get out of order during one season. The friable foulings on the fire tube upper surface and gas-tube convection bundles, especially near the reversing chamber significantly reduce the heat exchange and lead to the tubes and tube plate overheating [4]. Periodic blow down will not be able to remove the fouling from the fire tube and boiler tubes upper part. Therefore, for removing the heating surfaces foulings, the boiler needs to be regularly stopped, and the fire tube and gas-tube bundle tubes need to be cleaned through the manhole by the air-water jet. Under the boilers standard make-up of less than 0.75% of the water volume per hour, the cleaning is possible to be performed once a year or every two years. At the above standard make up (most of the old municipal boiler houses, where the hot water supply is not provided or heating networks are worn out), the cleaning should be performed once a month or every two months of the boilers operation. Many imported boilers do not have the manholes, through which the boilers can be cleaned and therefore their cleaning is very difficult. To extend such boilers lifetime, it is necessary either to demineralize the water (this technique is adopted in the European countries) or to use two circuits heat supply scheme and exclude the boiler circuit water losses.
Based on the numerical experiment, it is possible to propose the fire-tube boiler design changes for reducing the fouling formation velocity and determining the predicted accumulation place for removing. The calculation scheme is shown in figure 1.

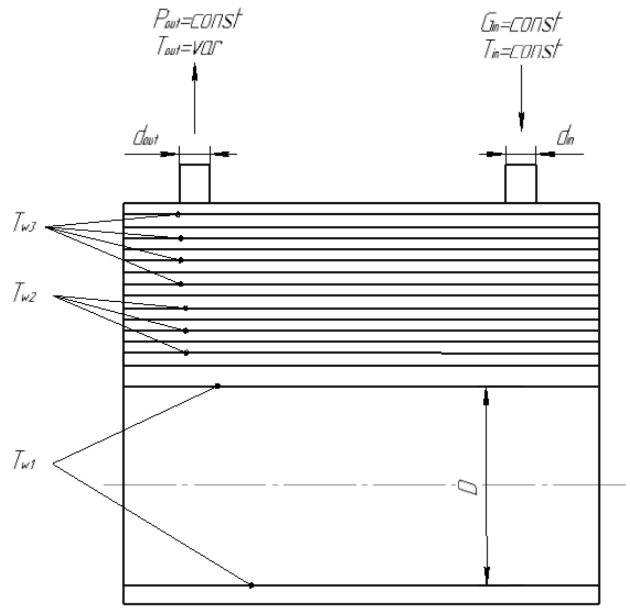


**Figure 1.** The calculation scheme of the fire-tube boiler water volume.

The mathematical model describing the fire-tube boiler processes includes the scaling model, the fouling motion model, the fuel combustion model, the heat exchange model from the combustion products to the wall and from the wall to the heat carrier is developed under the following main assumptions [9,11]: oxidizer is air; reacting gas is methane; the heat from combustion products to the wall is transferred by molecular diffusion, convection and radiation; the pressure gradient inside the boundary layer is zero; the total heat transfer at the wall-liquid interface is performed through the convection, and gas-wall one is done through the convection and radiation; the heat exchange surface fouling main types are scale and foulings. The fire-tube boiler heating surfaces slime sedimentation process was modelled in the software system ANSYS CFX [8].

## 3. Theory

Let us consider the dynamics patterns of the boiler water particulates system motion. For simulating the slime particles motion process, the multiphase model, in which the slime particles move in the flow, is used. The slime particles motion is represented as the slime particles assembly with individual characteristics, which motion is considered by using the non-steady differential equations for the individual slime particle and consists of the velocity, position, mass and temperature equations [8].

The slime particle motion is calculated by means of the current coordinate $x_i$ equation and takes into account the time step $\delta_t$:

$$x_i^n = x_i^o + v_{pi}^o \delta t \tag{2}$$

where indexes *"o"* and *"n"* correspond to the previous and new time variable, correspondingly, and $v_{p\,i}$ is the slime particle velocity.

Each slime particle is assumed to move in a continuous flow – a liquid medium. The forces effecting the slime particles produce the slime particle acceleration due to the excellent velocities of the latter and the flow. Besides, these forces act on the flow. For such particles, the following equation can be recorded:

$$m_p \frac{dU_p}{dt} = F_D + F_B + F_R + F_{VM} + F_p + F_{BA} \tag{3}$$

the following forces are on the right side of the equation: $F_D$ is the aerodynamic resistance force; $F_B$ is the lifting force; $F_R$ is the force caused by the rotational motion; $F_{VM}$ is the force caused by the particle acceleration against the liquid; $F_P$ is the force caused by the pressure gradient; $F_{BA}$ is the Basset force.

## 4. Experimental results

In the process of conducting the numerical experiment and structural changes (the fire tube transverse finning), the data of the fire tube surface fouling formation velocity dependence on the particles concentration shown in figure 2, were obtained. The given dependences were obtained for a 200 kW fire-tube boiler with a fire tube of $d_{in}$×δ=0.46×0.01 m.

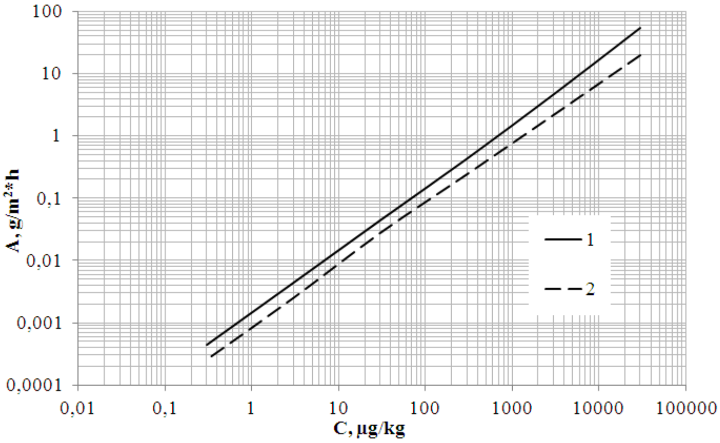


**Figure 2.** The fouling formation velocity dependence on the heat carrier particles concentration: 1 is the fire tube smooth surface; 2 is the fire tube finned surface.

Figure 2 shows that the use of the fire tube transverse finning results in the fouling formation velocity reduction.

## 5. Results discussion

Fire tube fouling formation velocity is reduced due to more intense convective processes of the interfins volume, which detailed description is discussed below (figure 3).

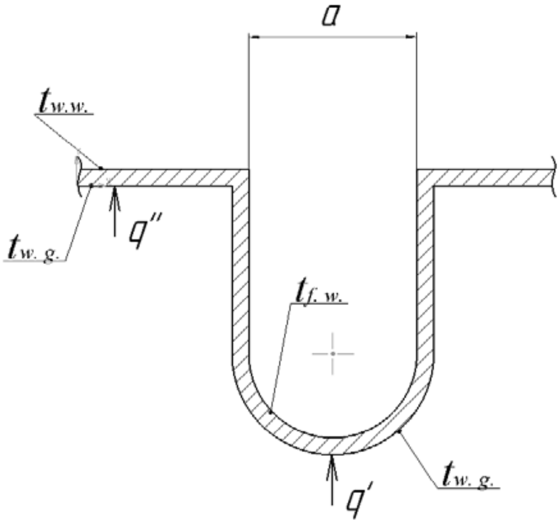


**Figure 3.** The finned fire tube surface heat fluxes density distribution scheme.

The fire tube fin heat fluxes distribution scheme is presented in figure 3. The variables have the following values: q'=64133 W/m$^2$, q"=39960 W/m$^2$, $t_{w.w}$=138 °C; $t_{f.w}$=165 °C, $t_{w.g.}$=146 °C, $t_{f.g}$=180 °C, and the heat transfer coefficient value varies from 720 to 9159 W/(m$^2$*K) when moving from the fin bottom to the top.

Taking into consideration the above, the dependence of the average heat transfer coefficient over the fire tube surface on the heat carrier side on the fin width (figure 4) according to the following formula is obtained [7]:

$$\dot{\alpha} = \frac{\frac{1}{F_o}\int_0^{F_o} q_c dF}{\frac{1}{F_o}\int_0^{F_o} \Delta t dF} \quad (4)$$

where $F_o$ is the averaging surface area.

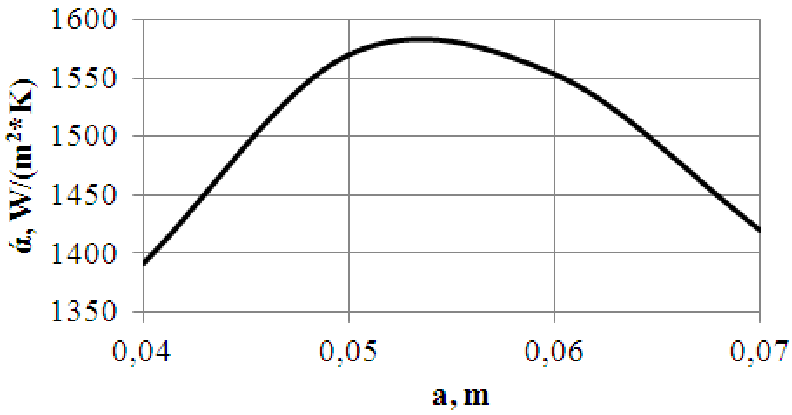


**Figure 4.** The dependence of the average heat transfer coefficient of the finned fire tube on the heat carrier side on the fin width.

Figure 4 shows that the maximum value corresponds to the fin width equal to 0.054 m. The fire tube surface finning results in the heat flux density decrease, and due to the heat carrier temperature

IOP Conf. Series: Journal of Physics: Conf. Series **1210** (2019) 012139 doi:10.1088/1742-6596/1210/1/012139

increase between the fins, the heat exchange process at boiling the heat carrier will begin at the heat flux lower density ($q \geq 40$ kW/m$^2$), and in turn rising bubbles intensify near-wall region convective phenomena and prevent the fire tube sliding.

## 6. Conclusions

The boiler fire tube proposed design reduces the fouling formation velocity to 50% and provides slime accumulations in the boiler lower part, where it is easily removed by blowing.

## 7. References

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